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(54) **GAS SAMPLING CELL**

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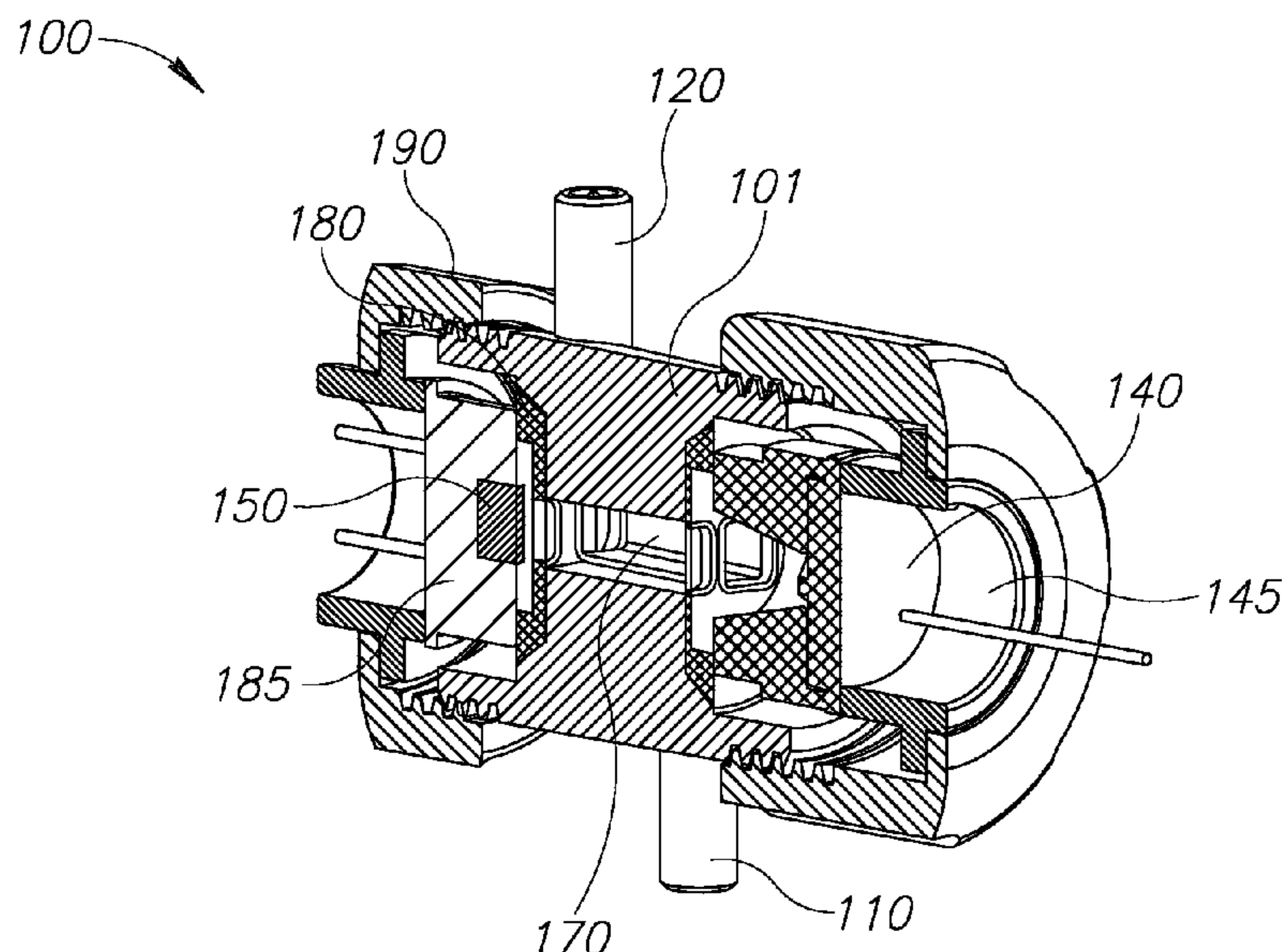
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(57) **ABSTRACT**

A sensor for detecting concentration of a component in a
breath sample including a gas sampling cell having an inlet,
an outlet, a light source, a first light detector, a sampling
channel configured to receive gas samples from the inlet; the
sampling channel defining a light path between said light
source and said first light detector; and a volume occupying
material located within the sampling channel, the volume
occupying material having an absorption coefficient for
mid-infra-red light below 0.5 cm^{-1} at room temperature.

19 Claims, 1 Drawing Sheet



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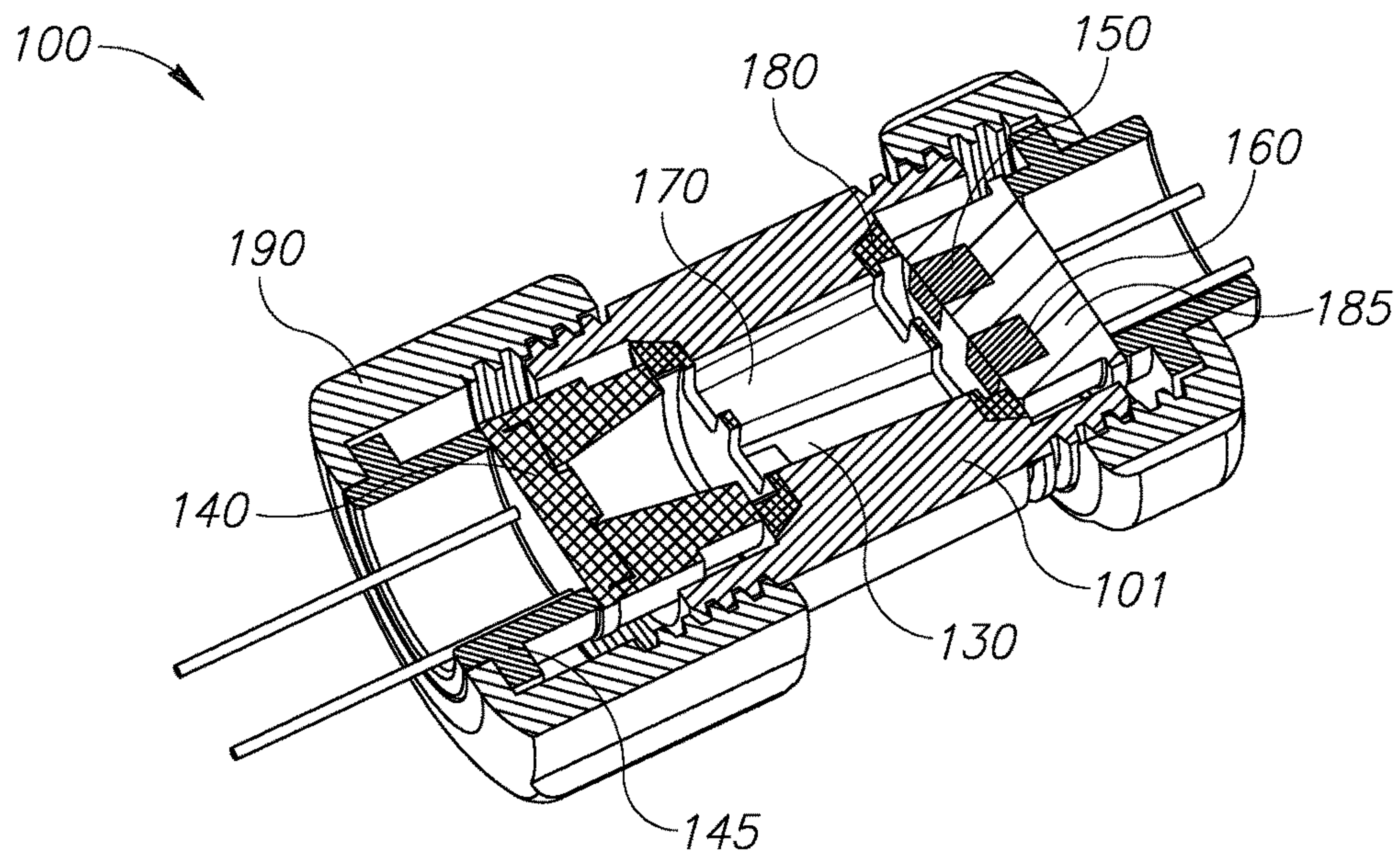


FIG.1A

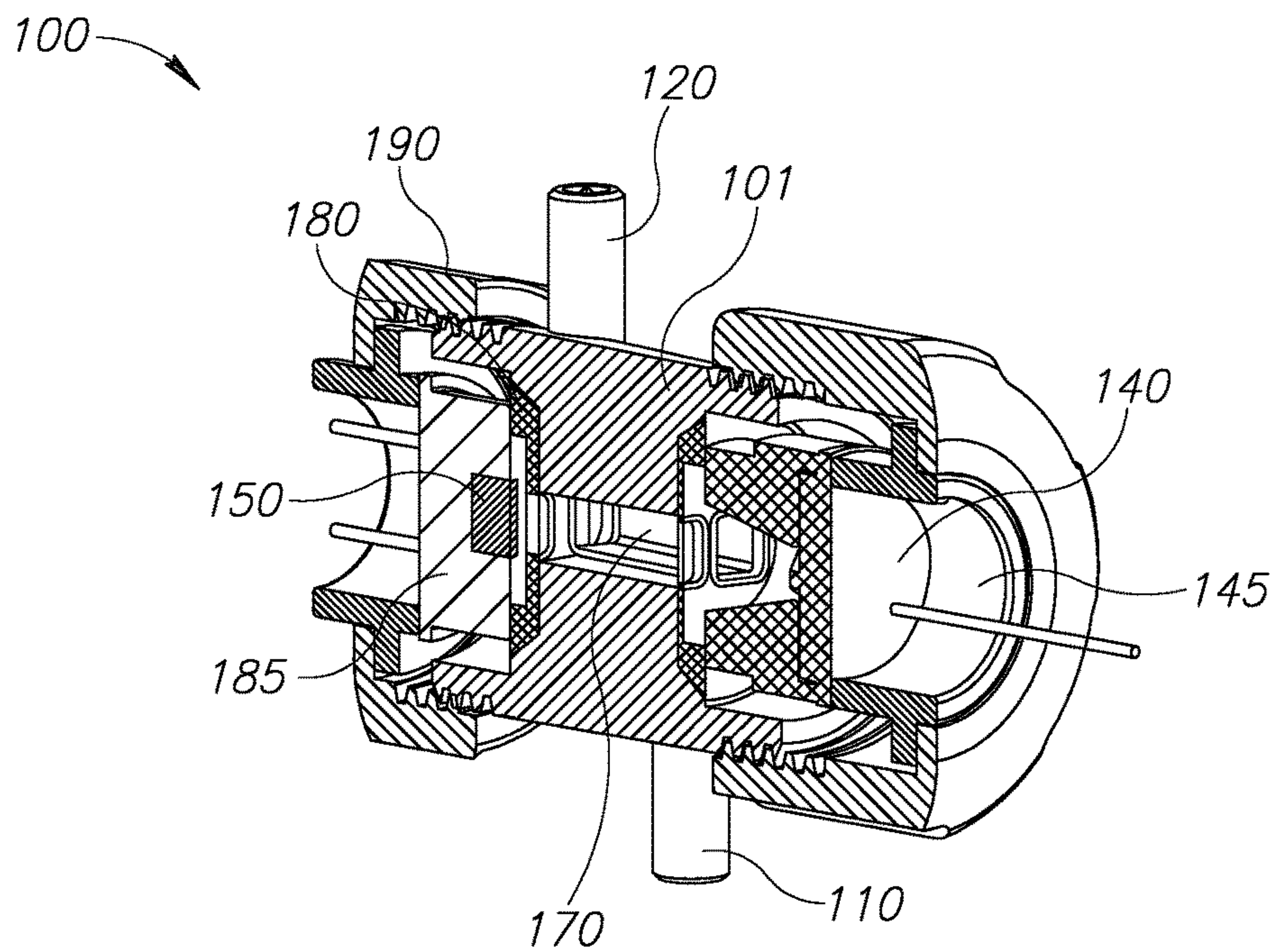


FIG.1B

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GAS SAMPLING CELL

TECHNICAL FIELD

The present disclosure generally relates to the field of 5 breath sampling and gas sampling sensors.

BACKGROUND

Determination of components (e.g. CO₂) in a gas mixture 10 (e.g. a breath sample) is based on the fact that gases like CO₂ absorb light at a specific wavelength in the infrared light spectrum. Detection of a concentration of a gas component such as CO₂ is therefore typically accomplished by passing 15 a beam of infra-red light across the gas sample. Presence of CO₂ in the gas leads to a reduction in the amount of light in the spectrum and, based upon the reduction, the concentration of CO₂ in the sample is inferred.

SUMMARY

The present disclosure relates to novel gas sampling 25 sensors for detecting concentration of a component, such as, but not limited to, CO₂, in a breath sample. The sensor includes a gas sampling cell having an inlet, an outlet, a light source, a first light detector, a sampling channel configured to receive gas samples from the inlet, and a volume occupying material located within the sampling channel, the volume occupying material having an absorption coefficient 30 for mid-infra-red light below 0.5 cm⁻¹ at room temperature.

Advantageously, the volume occupying material located within the sampling channel of the sensor reduces the volume of the sampling cell. The reduction in sampling cell volume enables an increased discharge rate of the gas inside the cell and consequently increases the response time of the sensor, as compared to the common sampling cells. This is particularly important for high breathing rates (e.g. more than 30 breaths per minute), as is, for example, typical in 40 infants.

Advantageously, the reduced cell volume is achieved with minimal interference with the light path between the light source and the light detector. This is due to the volume occupying material's low absorption coefficient in the absorption spectrum of the gas causing only negligible attenuation of the infrared radiation propagating through the volume occupying material.

Furthermore, due to the low absorption coefficient of the volume occupying material, the material may occupy part of 50 the sampling channel, essentially along its entire length, such that light, emitted by the light source, reaches a first light detector (e.g. a reference light detector) basically without encountering the gas sample present in the remainder of the sampling channel. As a result, the need for a separate reference channel, sampling a reference gas, such as ambient air, is obviated. This, since emitted light propagated through the volume occupying material and detected by a reference light detector may serve as a reference to light emitted from the light source, propagated through the breath 60 sample and detected by the main light detector. This is important since CO₂ tends to leak or diffuse from the main channel to the reference channel, thereby compromising the accuracy of the measurements.

According to some embodiments, the boundaries of the 65 volume occupying material and/or the edges of the sampling channel may be coated with a reflective material. This may

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advantageously ensure that radiation propagating through the breath sample will be reflected back if reaching the material.

According to some embodiments, there is provided a sensor for detecting a concentration of a component in a breath sample, the sensor including a gas sampling cell including an inlet, an outlet, a light source, a first light detector, a sampling channel configured to receive gas samples from the inlet; and a volume occupying material 10 located within the sampling channel, the volume occupying material having an absorption coefficient for mid-infra-red light below 0.5 cm⁻¹. According to some embodiments, the sampling channel may define an optic path between the light source and the first light detector. According to some 15 embodiments, the component is CO₂.

According to some embodiments, the volume occupying material may have an absorption coefficient for mid-infra-red light below 0.3 cm⁻¹. According to some embodiments, 20 the volume occupying material may have an absorption coefficient for mid-infra-red light below 0.1 cm⁻¹.

According to some embodiments, the volume occupying material may occupy between 25%-75% of the volume of the sampling channel. According to some embodiments, the volume occupying material may occupy between 35%-65% of the volume of the sampling channel.

According to some embodiments, the volume occupying material may include Sapphire, Silicon (Si), Germanium (Ge), Zinc Selenide (ZnSe) or any combination thereof. 30 According to some embodiments, the volume occupying material may include Sapphire. According to some embodiments, the volume occupying material may be made of Sapphire.

According to some embodiments, the light source may be 35 an infra-red (IR) light source.

According to some embodiments, the first light detector may include a first optical filter. According to some embodiments, the first light detector may include a second optical filter. According to some embodiments, the first optical filter 40 may be configured to transmit light having a first wavelength; and the second optical filter may be configured to transmit light having a second wavelength.

According to some embodiments, the gas sampling cell may further include a reference light detector. According to 45 some embodiments, the reference light detector may include a first and a second optical filter. According to some embodiments, the first optical filter may be configured to transmit light having a first wavelength, and the second optical filter may be configured to transmit light having a second wavelength.

According to some embodiments, the path length between the light source and the first light detector and/or the reference light detector may be in the range of 5-15 mm.

According to some embodiments, the distance between a 55 first end of the volume occupying material and the light source may be less than 5 mm. According to some embodiments, the distance between a second end of the volume occupying material and the first light detector and/or the reference light detector may be less than 5 mm.

According to some embodiments, the wall of the volume occupying material may be covered with a reflective material. According to some embodiments, the wall of the sampling channel may be covered with a reflective material.

According to some embodiments, the sensor may have a 65 response time of less than 100 ms.

According to some embodiments, the gas sampling cell may be devoid of a reference channel.

Certain embodiments of the present disclosure may include some, all, or none of the above advantages. One or more technical advantages may be readily apparent to those skilled in the art from the figures, descriptions and claims included herein. Moreover, while specific advantages have been enumerated above, various embodiments may include all, some or none of the enumerated advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

Examples illustrative of embodiments are described below with reference to figures attached hereto. In the figures, identical structures, elements or parts that appear in more than one figure are generally labeled with a same numeral in all the figures in which they appear. Alternatively, elements or parts that appear in more than one figure may be labeled with different numerals in the different figures in which they appear. Dimensions of components and features shown in the figures are generally chosen for convenience and clarity of presentation and are not necessarily shown in scale. The figures are listed below.

FIG. 1A and FIG. 1B schematically illustrate cross-sectional views of a gas sampling cell, according to some embodiments.

DETAILED DESCRIPTION

In the following description, various aspects of the disclosure will be described. For the purpose of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the different aspects of the disclosure. However, it will also be apparent to one skilled in the art that the disclosure may be practiced without specific details being presented herein. Furthermore, well-known features may be omitted or simplified in order not to obscure the disclosure. Additionally, it is to be explicitly understood that any combination of any one or more of the disclosed embodiments may be applicable and is within the scope of the disclosure.

According to some embodiments, there is provided a sensor for detecting a concentration of a component in a breath sample. The sensor includes a gas sampling cell having an inlet, an outlet, a light source, a first light detector, a sampling channel and a volume occupying material having an absorption coefficient for mid-infra-red (IR) light at room temperature, which allows IR light to propagate there-through, essentially undisturbed.

According to some embodiments, the sensor may include a carbon dioxide (CO_2) sensor, and the gas component may be exhaled CO_2 . According to some embodiments, the sensor may include a nitric oxide (NO) sensor, and the gas component may include exhaled NO. According to some embodiments, the sensor is configured for side-stream capnography.

As used herein, the term “essentially undisturbed” with regards to the propagation of light may refer to light, or a spectrum thereof, being transmitted through the volume occupying material while less than 1%, less than 0.5%, or less than 0.1% thereof is absorbed. According to some embodiments, the volume occupying material may be essentially transparent to the IR light.

According to some embodiments, as used herein, the term “volume occupying material” may refer to a material positioned within a sampling channel of a gas sampling cell, thereby occupying part of the sampling channel’s volume. According to some embodiments, the volume occupying material may be a material having a predetermined absorp-

tion coefficient for mid-infra-red light. According to some embodiments, the volume occupying material may have an absorption coefficient for mid-infra-red light at or below 0.5 cm^{-1} . According to some embodiments, the volume occupying material may have an absorption coefficient for mid-infra-red light at or below 0.3 cm^{-1} . According to some embodiments, the volume occupying material may have an absorption coefficient for mid-infra-red light at or below 0.1 cm^{-1} . According to some embodiments, the term “absorption coefficient”, “attenuation coefficient” and “extinction coefficient” may be interchangeably used and refer to the distance into a material into which light of a particular wavelength can penetrate before its intensity is reduced to $1/e$ of its initial value. The absorption coefficient depends on the material and on the wavelength of light, which is being absorbed. According to some embodiments, the absorption coefficient is measured at room temperature. As used herein, the term “mid-infra-red” and “mid-IR” may refer to IR with a wavelength in the range of or $3\text{-}5 \mu\text{m}$. Each possibility is a separate embodiment.

According to some embodiments, the volume occupying material may include Sapphire, Silicon (Si), Germanium (Ge), Zinc Selenide (ZnSe) or any combination thereof. Each possibility is a separate embodiment.

According to some embodiments, the volume occupying material may be located within the sampling channel. As used herein, the term sampling channel may refer to a compartment configured to enable sampling of breath using optics. According to some embodiments, the sampling channel enables an optic path between the light source and the first light detector.

According to some embodiments, the sampling cell further includes a reference light detector. According to some embodiments, the sampling channel enables an optic path between the light source and the reference light detector.

According to some embodiments, the gas sampling cell includes only a single gas sampling channel. According to some embodiments, the sampling channel enables detection of light propagated through a breath sample (breath sampling) as well a light propagated through the volume occupying material essentially without encountering the sample (reference). According to some embodiments, breath sampling and reference measurements, may be performed simultaneously from the (single) sampling channel. According to some embodiments, the gas sampling cell may be devoid of a distinct reference sampling channel.

According to some embodiments, the volume occupying material may occupy about half of the sampling channel, such as, but not limited to, 25%-75%, 35%-65% or 40%-60% of the sampling channel. Each possibility is a separate embodiment. According to some embodiments, the volume occupying material may occupy essentially the entire optic path between the light source and the reference light detector. It is understood that due to the volume occupying material occupying about half of the sampling channel, the volume of the cell is reduced by about half compared to common sampling cells. As a result, the discharge rate of the gas inside the cell is doubled, enabling an approximately 50% reduction in the response time of the sensor. According to some embodiments, the sensor may have a response time of 200 milliseconds (ms) or less, 100 ms or less, 50 ms or less, 25 ms or less, or 15 ms or less. Each possibility is a separate embodiment. It is understood that such fast response times may be particularly advantageous when monitoring subject’s with high respiration rates, such as, but not limited to, neonates and infants.

According to some embodiments, the volume occupying material may extend along the entire length (but essentially half the width) of the sampling channel. According to some embodiments, the term “length” with regards to the sampling channel may refer to the axis of the sampling channel extending from the light source to the light detector (i.e. the distance in which the light passes through the gas, also called the path length). According to some embodiments, the length of the sampling channel may be in the range of 3-15 mm, 3-10 mm, 5-15 mm or 5-10 mm. Each possibility is a separate embodiment. According to some embodiments, the length of the sampling channel may be 8 mm.

According to some embodiments, the term “essentially entire length” may refer to more than 80% of the length, more than 90% of the length, more than 95% of the length, more than 98% of the length or more than 99% of the length. Each possibility is a separate embodiment. According to some embodiments, the distance between a first end of the volume occupying material and the light source may be less than 5 mm, less than 3 mm, less than 1.5 mm, less than 1 mm or less than 0.5 mm. Each possibility is a separate embodiment. According to some embodiments, the distance between a second end of the volume occupying material and the reference light detector may be less than 5 mm, less than 3 mm, less than 1.5 mm, less than 1 mm or less than 0.5 mm. Each possibility is a separate embodiment. It is understood that by minimizing the space between the volume occupying material and the light source and/or light detector, the amount of breath sample in this space, and thus the amount of CO₂ capable of absorbing light propagated through the volume occupying material, and thus affecting reference readings, is negligible.

According to some embodiments, the space between the volume occupying material and the light source and/or reference light detector may be filled with an optically clear adhesive (OCA) and/or an elastomeric seal. The OCA and/or the elastomeric seal may essentially eliminate the air gap between the volume occupying material and the light source and/or light detector, thereby further preventing the breath sample from affecting reference readings.

According to some embodiments, one or more walls of the volume occupying material may be covered with a reflective material, such as, but not limited to, gold. According to some embodiments, one or more walls of the sampling channel is covered with a reflective material, such as, but not limited to, gold. It is understood that by covering the walls of the volume occupying material and/or of the sampling channel with a reflective material may redirect escaping gas to the optic path between the light source and the first light detector, thereby ensuring optimal readings.

According to some embodiments, the first light detector may include a first optical filter. According to some embodiments, the filter may be configured to selectively transmit light absorbed by the component (e.g. CO₂) in the gas. According to some embodiments, the filter may be a band-pass filter centered at 4.26 μm. According to some embodiments, the first light detector may include a second optical filter configured to transmit light having a wavelength unaffected by the component. According to some embodiments, the second optical filter may be a bandpass filter centered at 3.95 μm.

According to some embodiments, the light source may be an infra-red (IR) light source, such as a black body, a light emitting diode or diode laser.

According to some embodiments, the first light detector and the reference detector may be the same or different detector. According to some embodiments, the first light detector

and the reference light detector may be the same detector. In such instance, sample and reference measurements may be made at different times or utilizing different parts of the detector. According to some embodiments, the first light detector and the reference light detector may be separate but identical detectors. According to some embodiments, the first light detector and the reference light detector may be separate but different detectors. According to some embodiments, the first light detector and the reference detector may include a same or different filter.

Reference is now made to FIGS. 1A and 1B, which schematically show cross-sections of a gas sampling cell **100**, according to some embodiments. Gas sampling cell **100** includes a cell body **101** having an inlet **110**, an outlet **120**, and a sampling channel **130** configured to receive gas samples (e.g. breath samples) from inlet **110**. Gas sampling cell **100** further includes a light source **140** positioned at a first end of sampling channel **130**, within or in proximity to light source adaptor **145**, and a detector body **185** including a main (first) light detector **150** and a reference light detector **160** at a second end of sampling channel **130**. Sampling channel **130** includes a volume occupying material **170** (e.g. sapphire) located along the length of sampling channel **130** occupying the optical path between light source **140** and reference light detector **160**. Consequently, light emitted by light source **140** propagates through volume occupying material **170** and reaches reference light detector **160** essentially without encountering the gas sample flowing within the gas sampling cell **100**. Optionally, sampling cell **100** includes an elastomeric seal **180** configured to seal off space between volume occupying material **170** and main light detector **150** and/or reference light detector **160**. Furthermore, sampling cell **100** may optionally include a tightening element **190** at least partially covering sampling cell **100**. Advantageously, the remainder of sampling channel **130** configured to contain the gas sample is reduced by approximately 50%, thereby significantly reducing the response time of the measurements.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, or components, but do not preclude or rule out the presence or addition of one or more other features, integers, steps, operations, elements, components, or groups thereof.

While a number of exemplary aspects and embodiments have been discussed above, those of skill in the art will recognize certain modifications, additions and sub-combinations thereof. It is therefore intended that the following appended claims and claims hereafter introduced be interpreted to include all such modifications, additions and sub-combinations as are within their true spirit and scope.

The invention claimed is:

1. A sensor for detecting concentration of a component in a breath sample, the sensor comprising a gas sampling cell comprising:

- an inlet;
- an outlet;
- a light source;
- a first light detector;

a sampling channel configured to receive gas samples from the inlet and comprising a length extending from a first end to a second end of the sampling channel; the

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sampling channel defining an optic path along the length between the light source and the first light detector, wherein the light source is positioned adjacent to the first end and the first light detector is positioned adjacent to the second end; and

a volume occupying material located within the sampling channel, wherein the volume occupying material extends the length of the sampling channel from the first end to the second end, the volume occupying material having an absorption coefficient for mid-infrared light below 0.5 cm^{-1} .

2. The sensor of claim 1, wherein the volume occupying material having an absorption coefficient for mid-infrared light below 0.3 cm^{-1} .

3. The sensor of claim 1, wherein the volume occupying material having an absorption coefficient for mid-infrared light below 0.1 cm^{-1} .

4. The sensor of claim 1, wherein the volume occupying material occupies between 25%-75% of the volume of the sampling channel.

5. The sensor of claim 1, wherein the volume occupying material occupies between 35%-65% of the volume of the sampling channel.

6. The sensor of claim 1, wherein the volume occupying material comprises sapphire, silicone, germanium or any combination thereof.

7. The sensor of claim 1, wherein the light source is an infra-red (IR) light source.

8. The sensor of claim 1, wherein the first light detector comprises a first optical filter.

9. The sensor of claim 8, wherein the first light detector comprise a second optical filter; wherein the first optical

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filter is configured to transmit light having a first wavelength; and wherein the second optical filter is configured to transmit light having a second wavelength.

10. The sensor of claim 8, wherein the gas sampling cell further comprises a reference light detector.

11. The sensor of claim 10, wherein the reference light detector comprise a first and a second optical filter; wherein the first optical filter is configured to transmit light having a first wavelength; wherein the second optical filter is configured to transmit light having a second wavelength.

12. The sensor of claim 10, wherein a path length between the light source and the first light detector and/or the reference light detector is in the range of 5-15 mm.

13. The sensor of claim 10, wherein a distance between a first end of the volume occupying material and the light source is less than 5 mm.

14. The sensor of claim 10, wherein a distance between a second end of the volume occupying material and the first light detector and/or the reference light detector is less than 5 mm.

15. The sensor of claim 1, wherein a wall of the volume occupying material is covered with a reflective material.

16. The sensor of claim 1, wherein a wall of the sampling channel is covered with a reflective material.

17. The sensor of claim 1, wherein the gas sampling cell is devoid of a reference channel.

18. The sensor of claim 1, wherein the component is CO_2 .

19. The sensor of claim 1, wherein the component is Nitric Oxide.

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